

USE OF CAD SYSTEM TO ANALYZE COLLISION POSSIBILITY DURING TRANSPORTATION OPERATIONS

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Abstract:

Nowadays designing of selected areas of mines underground workings can be effectively improved by numerical simulation. This, in fact, would result in the more reliable design process, significantly reduced designing costs and efforts, and improvement of the mines staff's safety. Mine transportation of materials and people in underground workings is realized by use of mine railway system (on the main transportation routes), floor-mounted railway and suspended monorail (in a department transportation). Transportation is realized on tracks placed on the floor of working (floor-mounted rail transportation, using transportation platforms) or on rails suspended to roadway support (suspended rail transportation, using modular carrying sets (high-load beams)). The increasing size and weight of the transported machines and other equipment require planning the transportation system based on analyses of transportation routes as regards possibility of collision between transported loads and roadway support components, the equipment or other machines, that can be the obstacles or that can cause hazard during transportation, to select properly transportation machines. In case of improper selection, this may be the reason of hazard during transportation (dynamic impact of a mass of several tons). The developed method involves two-pronged generation of input data for collision analysis in a CAD software environment. Data regarding the route and constraints resulting from the dimensions of the roadway excavation are transferred in a CAD file format. Data regarding the overall dimensions of the means of transport (suspended monorail or floor-mounted railway) and simulation parameters are developed in a dedicated software environment in the form of a website. The methodological assumptions of the problem are presented, and its implementation into CAD software (AutoCAD) environment is given. Finally, an example of the application of the described method to analyze collision possibility during transportation operations, using floor-mounted railways and suspended monorails, during transportation of big-size load is given (transportation of longwall powered roof support). Developed software is used in Jastrzębska Coal Company S.A. as a Safe Trans Design, by the designers of transportation systems, during the verification of transport system designs, against safety criteria.

Key words: collision detection, numerical simulation, outline of transported load, floor-mounted railways, suspended monorails

INTRODUCTION

Collision detection in CAD (Computer-Aided Design) refers to the process of identifying when two or more components of a design intersect or interfere with each other in a way that could cause physical problems in the real world. This is critical in mechanical, architectural, robotics and industrial design workflows to ensure parts fit and move together without unintended contact.

It is possible to distinguish between the following types of collision detection:

1. Static collision detection [1]:
 - Checks if parts overlap in a fixed configuration.
 - Common in assembly verification.
2. Dynamic collision detection [2]:

- Simulates movement to detect collisions over time.
- Used for moving assemblies or kinematic simulations.

3. Clearance analysis [3, 4]:

- Evaluates the space between components to ensure there's sufficient room for operation or manufacturing tolerances.

Collision detection can be checked between:

- Bounding Volumes: simplified shapes (boxes, spheres) are used around objects to quickly detect potential collisions.
- Mesh-based: more precise – compares the actual geometry (e.g., faces, edges) of parts.

- Constraint-based: in assemblies, CAD software can apply rules (e.g., hinge motion) and detect when parts violate constraints or exceed limits.

Common CAD tools with build-in collision detection:

- SolidWorks: has interference detection and motion simulation.
- Autodesk Inventor: includes dynamic simulation with collision detection.
- PTC Creo: offers assembly checks and dynamic interference analysis.
- Siemens NX/CATIA: advanced options for real-time collision monitoring during movement.

Collision detection is used to:

- Assembly verification: ensures all parts fit correctly without clashes.
- Motion simulation: validates kinematic paths of mechanisms or finds the outline of the transported load.
- Manufacturing: prevents tool paths from colliding with fixtures or parts.
- Robotics: avoids arm or component collisions during motion planning.

Collision detection is one of the most important geometric queries. A basic problem in collision detection is to produce an object's continuous motion from its starting point to its end point (obtaining the outline of the transported load), avoiding collisions with known obstacles. The collision detection method typically refers to the computational problem of detecting the intersection of two or more objects. The motion of an object and an obstacle's geometry are described in a 2D or 3D workspace, whereas the motion path is represented mainly as a continuous line, within a 2D or 3D workspace. Solving collision detection problems requires the comprehensive use of concepts from linear algebra and computational geometry. The objective of the collision detection method is to report a geometric contact when it is about to occur or has actually occurred. It is typically used in order to simulate the physics of moving objects, or to provide the geometric information that is needed in future work (outline of the transported load), for example, planning of the underground transportation operation [5]. Collision analysis can also be performed in a more advanced software environment, such as the MBS (Multi-Body System) numerical method [6]. In this case, in addition to detecting potential collisions, it is possible to determine contact forces and reactions in the joints of a given assembly. However, this method is more time-consuming, requiring the creation of computational models and conducting calculations, which can be time-consuming.

Transportation of materials in underground mine workings inside mining areas is realized mainly with the use of floor-mounted railways (using transportation platforms, Figure 1a [7, 8]) or by suspended monorails (using modular carrying sets – high-load beams), Figure 1b [9]). Transported load is usually fixed to the transportation device and stabilized by the chains or traverses. The ability of a suspended monorail to pass by obstacles such as conveyors, drives, and other underground equipment that can be

found in roadways on the transportation routes is its advantage.

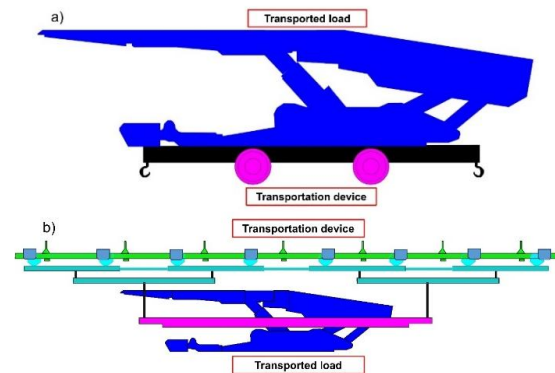


Fig. 1 Example of transportation of big-size load using: a) transportation platform; b) modular load-carrying unit (high-load beam)

Source: [7, 8, 9].

Suspended monorails are especially used in the roadways of weak floor rocks, which are prone to be deformed. Further, suspended monorails facilitate reloading of materials in the transferring stations. Suspended monorails are very popular in Polish underground coal mines. Floor-mounted railways are an important aid in the case when it is necessary to re-equip longwalls fitted with powered-roof supports of high weight or in the case of high inclination of the transportation track. Owing to traction possibilities, floor-mounted railways provide an excellent complement to other transportation systems. An increased size of transported equipment requires the design of transportation systems on the basis of analyses of the railway tracks regarding the possibility of collision of transported loads with the support and roadway equipment, especially during transportation of large or long materials. Further, suspended monorails facilitate reloading of materials in the transferring stations. Suspended monorails are very popular in Polish underground coal mines. Floor-mounted railways are an important aid in the case when it is necessary to re-equip longwalls fitted with powered-roof supports of high weight or in the case of high inclination of the transportation track. Owing to traction possibilities, floor-mounted railways provide an excellent complement to other transportation systems. An increased size of transported equipment requires the design of transportation systems on the basis of analyses of the railway tracks regarding the possibility of collision of transported loads with the support and roadway equipment, especially during transportation of large or long materials. Collision-free passage of the load during transportation operations, depends on the proper design of the track and the selection of the transportation system. Analysis of the possibility of collision on transportation routes is especially important in the case of the design of a transportation system when a decrease in the roadway cross-section as a result of a reaction of the surrounding rock mass should be considered. In addition, requirements regarding traffic clearances between elements of the transportation devices, the side wall and the floor has to be verified.

LITERATURE REVIEW

This article provides insights into various collision detection methodologies applied within CAD systems, ranging from real-time simulations to applications in augmented reality and large-scale construction projects. It presents the development and application of collision detection methods running within CAD systems across various industries. Computing collisions is of great interest to the computer graphics, video game, and robotics communities.

Collision detection between objects is critical for simulation, control, and learning for robotic systems. In paper [10], a DCOL: fast and fully differentiable collision-detection framework that detects collisions between a set of composable and highly expressive convex primitive shapes, has been proposed.

Collision detection is also essential to all robotics applications, as it enables robots to find safe paths to their goal states. However, traditional geometric collision detection methods generally require pre-existing workspace geometry representations; thus, they are unable to infer the collision detection function from sampled data when geometric information is unavailable. There are no cameras in the warehouse, nor are there measurements for every single object that passes through the warehouse. Instead of object geometry information, the primary way to build a collision detection function would be to learn from samples, i.e., learning-based approach. In paper [11], authors present DeepCollide, an implicit neural representation method for approximating the collision detection function from sampled collision data. In this paper, a DeepCollide was presented, a scalable, lightweight neural network method for the rapid approximation of the collision detection function in high DoF. Presented method could be most useful in situations where the obstacle and/or workspace geometry are not already known, but we do have sampled collision data from exploratory robot movements – traditional geometric collision checkers will not work in these cases. Collision Detection has several applications across the domains such as robotics, visual graphics, and fluid mechanics. It plays a significant part in several applications such as fluid mechanics, computer graphics, virtual reality, and path planning, for simulating real-world object behaviors. Collision Detection determines all the pairs of colliding objects along with any application-specific parameters such as point of collision, time of collision, or the volume displaced due to collision. In paper [12], authors present Mochi: a method to fast and exact collision detection. In paper [13], authors present an easy distance field-based collision detection scheme to detect collisions of an object with its environment. This scheme is able to manage collision detection between one object and its environment. The scheme can detect if the surfaces collide or if an element of the environment is included in the object but not if the object is included in an element of the environment. It only requires the meshes of the object and the scene; it does not rely on special representations.

Young drivers are a high-risk group for vehicle crashes due to inexperience in detecting an impending collision and are one group that may benefit from perceptual learning (PL) training. The PL could be used to improve performance in collision detection. Repeated exposure or practice with a visual task can improve visual performance. Successfully detecting and avoiding collisions is an important issue. Paper [14] provides that collision detection performance can be improved through training. Many applications in Computer Graphics require fast and robust 3D collision detection algorithms. In [15], authors presented and grouped these algorithms into four approaches: space-time volume intersection, swept volume interference, multiple interference detection and trajectory parameterization. A novel approach to collision detection with the human body in a material drape simulation system was developed and applied in [16]. The presented method was shown to compare favorably, both in terms of efficiency and ease of implementation, with a number of alternative strategies.

Article [17] presents a method based on numerical computations for collision avoidance between the toolholder (quill) and workpiece in ball nut grinding in a CAD environment. Besides collision avoidance, presented procedure is capable of determining the proper grinding angle with the prescribed safety gap between the toolholder and workpiece. The assembly model of the grinding environment was prepared with a Siemens PLM NX system while the interoperation between the assembly model of the CAD system and the mathematical software (parameter transfer and retrieving) was performed by the Maple NX CAD package.

METHODOLOGY OF RESEARCH

In Polish coal mines, designs of transportation system are developed by the Division for Preparation of Production in Mines and many of them are prepared with the use of the CAD designing system (mainly AutoCAD). Most of the drawing documentation of a transportation system design is developed in that system. AutoCAD is one of the CAD software. Possibility of writing own, author's applications, running inside CAD system, which automate certain tasks or make additional calculations, is one of advantages of these systems. These are so-called external applications, which run inside the CAD system and which extend possibilities of its use in different branches of industry.

Research work aiming at a development of tools aiding verification of designs of transportation systems in the light of safety criterion was started at the KOMAG Institute of Mining Technology in 2007 [18]. Analyses of collision of large-size loads and long loads, which are transported in roadways by mine underground railway, floor-mounted railways and suspended monorails are significant part of the verification procedures. Collision analysis on transportation routes is especially important in the case of designs of transportation system, in which reduction of area of roadway cross-section in a result of impact of surrounding rock mass should be considered [19].

Prototype of software tool was designed during realization of MINTOS European research project [20]. After adapting its functionality to the requirements of the end users (designers from the Production Preparation Department of the mines), the prototype was implemented in the mines of Jastrzębska Coal Company in 2013 [21]. The following regulations and drawing documentation were used during the development of the prototype tool and its implementation:

- The sizes of the clearances resulting from [22, 23].
- The drawings made by KWK Ziemowit mine as a part of transportation documentation, Figure 2a and 2c [24].
- The drawings made by KWK Borynia-Zofiówka Jastrzębie mine as a part of transportation documentation, Figure 2b [25].

Examples of collision analyses carried out are presented in: Figure 2a and Figure 2b (transportation by floor-mounted railway) and in Figure 2c (transportation by suspended monorail). Drawing's documentation of transportation system was obtained from Ziemowit and Borynia-Zofiówka.

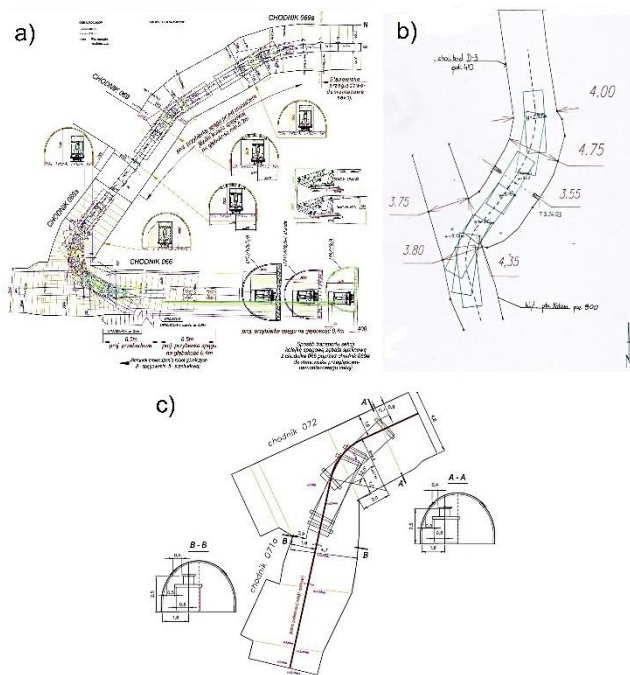


Fig. 2 Examples of collision analysis during big-size load transported by: a) and b) floor-mounted railway (electronic and paper documentation); c) suspended monorail (electronic documentation)

The drawings made by KWK Ziemowit mine and KWK Borynia-Zofiówka mine as a part of transportation documentation
Source: [24, 25].

Analysis of transportation route as regards possibility of collision is realized in CAD system (for example AutoCAD) or in paper documentation, by positioning of the load in the selected points of route and visual assessment of collision possibility. This task is especially difficult and time-consuming with use of suspended monorails, where load-carrying unit (high-load beam) is usually the transportation device. Kinematics of load-carrying unit on a bend

causes change of load trajectory from the axle of railway route, what significantly extends time required for collision analysis.

Supporting the designers in creation of new route of transportation system or in verification of the existing route of transportation system is the main task of software tool for collision analyses in underground transportation. In order to reduce the time of performing collision analyses, standardize the form of input data specifications and the form of the final results obtained, the module for collision analyses was developed (as part of the STD system). There are the following assumptions for the software tool for collision analyses, which runs in CAD environment:

- Software tool (collision analysis module) will be helpful for the designers of transportation system in testing the collision on the selected fragment of the route of mine underground railway, floor-mounted railway or suspended monorail.
- The module should be linked to the CAD program used to create drawing documentation of the transportation system design.
- Design of transportation system and drawing documentation are input data for the collision analysis.
- The collision analysis module should be run from the STD (Safe Trans Design) system and use the data stored in the system (data of the transportation platforms, high-load beams, transverse and longitudinal traverses).
- The module should allow collision analysis for flat models (2D models) – determining the envelope of the transported load, the envelope of the transportation device (transportation platform), the envelope of the traverses and the envelope of the clearances.
- Input data for collision analysis should be entered through a CAD graphics file and through a Web Form, available on the STD system website, in the collision analysis module.
- In order to document the input data, an input data form (dialog box) that contains all the necessary data for carrying out the simulation should be created.
- In order to simplify the entering of input data, it was assumed that the CAD file would contain only the route of the railroad and the outline of the workings. All other input data necessary for the analysis would be entered via a web form.
- The results of the collision analysis will be documented in the form of CAD graphic files, which will enable their further analysis and processing by mine's staff, and additionally, in the form of JPG bitmap files.

Analysis of transportation route as regards selection of route's fragments where collision might occur is the first stage of formulation of input data. Analysis of transportation system as regards selection of load, which can cause a risk of collision during transportation work, is the next stage of formulation of input data. Collision analyses on mine's transportation routes can be made with use of author's software [26, 27], developed at the KOMAG Institute of Mining Technology, which was written in

AutoLISP/VisualLISP programming language [28, 29], runs in AutoCAD environment and uses WEB software developed in PHP programming language [30, 31, 32, 33, 34]. Information's flow in collision's analysis module is presented in Figure 3.

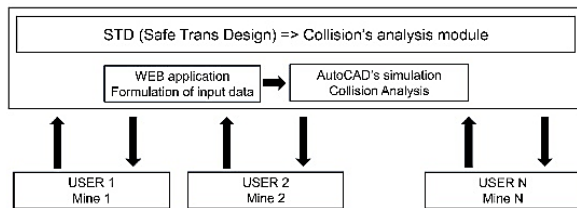


Fig. 3 Information's flow in collision's analysis module

Users of the STD system (from individual mines), on local workstations equipped with AutoCAD, prepare a DWG file with a selected part of the route and the outline of the workings. Then, via a web browser, they log into the STD system. After selecting the collision analysis module and specifying whether the analysis is for a floor-mounted railway or for a suspended monorail, they enter the remaining data necessary for the analysis via a web form. The results of the analysis, in the form of JPG files of the various

stages and steps of the simulation, are sent to the end's user in the form of a ZIP archive file.

The developed 2D collision analysis module consists of the following software components:

- The Web application, running from the STD system, for communication between the end user and the collision analysis module, running inside CAD program (AutoCAD).
- The text file, whose task is to provide the flow of input data from the Web application to the CAD program (AutoCAD), in which the collision analysis is performed.
- The collision analysis module, run from within a CAD program (AutoCAD), whose task is to build a numerical model (based on a text file of input data), run a simulation and return its results.

Web application

Its task is to obtain input data for the collision analysis module, via a Web Form displayed from the STD system. 2D collision analysis Web Form for floor-mounted railways, filled with sample input data is presented in Figure 4a. A Web Form for suspended monorails, filled with sample input data is presented in Figure 4b.

a)

b)

Fig. 4 Web form for 2D collision analysis, with examples of input data: a) for floor-mounted railways, b) for suspended monorails
Source: [26, 27]

The Web Form is divided into the following sections:

- Project data: name and description.
- Input data files: DWG (required) with railroad and outline of the workings (optional); JPG (optional) with outline of the workings.
- Transportation unit: transportation's platform or high-load beam.
- Transportation load and his orientation to transportation unit.
- Simulation's parameters: simulation's step and value of clearances.

Text file of input data

The output data from the web application is a text file, which is the input data for the collision analysis module. The text file contains the data necessary to build a computational model and simulate the passage of a transportation unit with a load along a railroad route.

Collision analysis module

The simulation software automatically realizes the passage of the transportation unit with the load on a railway track in given simulation step. After each step, it leaves a 'trace' of the transported load. After the simulation, all 'traces' of the load are combined in one outline, which shows the 2D surface (outline of the transported load) that is covered in a roadway by the transported load during a passage of the transportation unit (transportation platform or modular load-carrying unit). Results of simulation, in the form of JPG files, are returned to the end's user in the form of a ZIP archive file.

RESULTS OF RESEARCH

Described method was used to check the 2D collision opportunity in transportation task, transporting section of longwall powered roof support by the use of floor mounted railway (transportation platform) or by suspended monorail (high-load beam). The example below shows obtained results, both for transportation platform and for high-load beam (the same transportation route).

Transportation task

The design of the transportation route should be verified – 2D contour lines should be determined as follows: for the transported load; for the transportation device (for the transportation platform); for the traverses (for the high-load beam) and for the clearances. For the purpose of analysis, a part of the underground working that contains a transportation route was selected, Figure 5.

The transportation route is located in the same place in underground working both for floor-mounted railway (axis of the rails) and for suspended monorail (axis of the monorail). A big-size load (power roof support) with dimensions: 4000 [mm] (length) x 1500 [mm] (width) x 1100 [mm] (height) was selected to be transported. The total mass of transported load is 22500 [kg]. Transport of load is realized from point A to point B – starting and ending point for the transportation. There is no rotation of the

transported load in relation to the transportation platform.

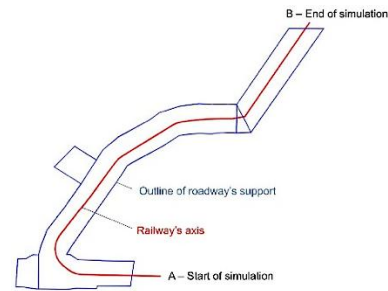


Fig. 5 Part of the underground working, selected for 2D collision analyses

The distance between successive traces of the load (simulation step) should be 250 [mm], while the size of the traffic clearances should be 400 [mm] (resulting from the regulations). The distance between successive traces of the load (simulation step) is the value by which the load will move along the route, while the size of the traffic passages is the minimum distance from the external dimensions of the load to potential obstacles on the transportation route.

For floor mounted railway (Figure 4a), a 'Becker-Warkop KSZS 350 kN (900 mm)' transportation platform should be used, for suspended monorail (Figure 4b), a 'FAMA MZN 300-230 kN' high-load beam should be used.

For floor mounted railway, the dimensions of the transportation unit and orientation of the transported load to transportation unit: A = 1760 [mm], B = 3800 [mm], C = 2500 [mm], D = 140 [mm], E = 225 [mm], F = 0 [mm], G = 1650 [mm], H = 5470 [mm], I = 0 [mm], J = 0 [mm].

For suspended monorail, the orientation of the transported load to transportation unit: A = 5470 [mm], B = 1650 [mm], C = 5400 [mm], D = 1770 [mm], E = 35 [mm], F = 5540 [mm], G = 2010 [mm].

Simulation's parameters:

- Simulation's step = 250 [mm].
- Traffic clearances = 400 [mm].

Results from numerical simulations

Results from simulation for floor mounted railway (transportation platform) are presented in Figure 6.

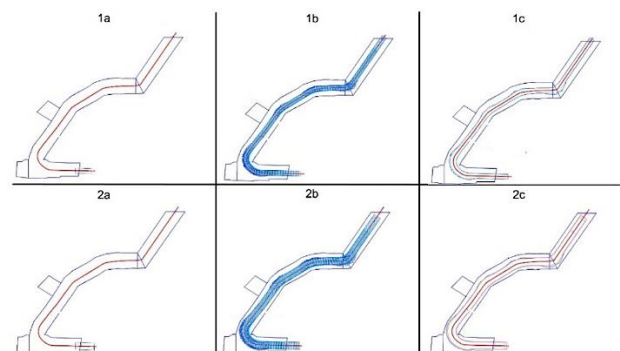


Fig. 6 Floor mounted railway – results from simulation
1 – traffic clearances = 0 [mm]; 2 – traffic clearances = 400 [mm]
a – start of simulation; b – traces of the transported load; c – outline of the transported load

Results from simulation for suspended monorail (high-load beam) are presented in Figure 7.

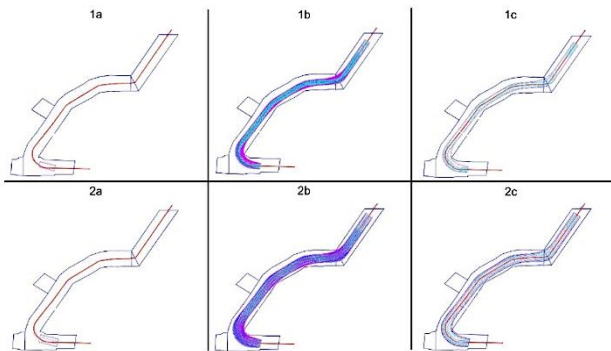


Fig. 7 Suspended monorail – results from simulation
1 – traffic clearances = 0 [mm]; 2 – traffic clearances = 400 [mm]
a – start of simulation; b – traces of the transported load;
c – outline of the transported load

DISCUSSION

Using the developed software, the 2D outlines of: transported load, transportation unit (for transportation platform) and traverses (for high-load beam) have been obtained in a result of simulation. These outlines can be additionally inscribed in contour lines of longitudinal section of the rail route, what is a further help to a designer during analysis of possibility of collision occurrence on a selected fragment of the route.

The execution time for simulation varied from 85 [s] (floor-mounted railway) to 160 [s] (suspended monorail), where simulation step = 250 [mm] and selected length of the route = 89 [m] (analyzed length = 82 [m]). The use of CAD simulations significantly reduces the time needed to analyze the selected fragment of the route, compared to traditional methods, and allows the designer to focus on the variants of load's transport and route's location in the working.

Conclusions of the simulation examples carried out:

- For a suspended monorail, where the transportation device is a modular load-carrying unit (high-load beam), there is a possibility to collision between the transported load and the working. Potential places of collision were marked in Figure 8 as red circles. To avoid the collision occurrence, the following solutions can be made: reconstruction of parts of the working, relocation of the rail route, transportation of the load in parts.

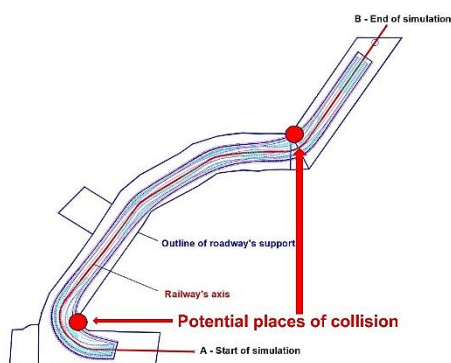


Fig. 8 Suspended monorail – potential places of collision

- The developed collision analysis tool is helpful when used for transport using suspended monorails, where the transportation unit is a modular load-carrying unit (high-load beam). In this case, it is necessary first to determine the kinematic chain of the transportation unit at a given point of the route, and then to orient the traverses and the transported load in relation to the transportation unit. This increases the time of analysis.
- The difference in the obtained outline of the transported load is due to the fact, that for transport using floor-mounted railway (transportation platform), the transported load deviates from the axis of the rail to the outside of the working, whereas for transport using suspended monorail (modular load-carrying unit), the transported load deviates from the axis of the rail to the inside of the working.
- It is advisable to move the axis of the railway from the axis of the working: to the outside (floor-mounted railway) or to the inside (suspended monorail).
- For a suspended monorail, it is advisable to extend the selected fragment of the route (start point and end point of the simulation), in order to build a kinematic chain of the transportation unit. The start point of the simulation (A) is the point of contact with the rail of the first trolley of the transportation unit. The end point of the simulation (B) is the point of contact with the rail of the last trolley of the transportation unit.
- If the direction of transport must be changed (for the same input data), in order to carry out the collision analysis again, the direction of the polyline showing the route of the rail should be changed.

CONCLUSIONS AND FUTURE WORK

The article presented a tool, developed at KOMAG Institute, that enables to check the collision's possibility for loads transported by floor-mounted railways and suspended monorails. Developed tool can significantly support the designers of underground transportation systems and is designed to aid planning, organizational and training activities undertaken in management of transportation safety in mines. It will be also possible to use the tool as the didactic material as regards safe transportation process, which include hazards to the employees working in the area of transportation operations. The presented method of analysis of the collision's possibility for floor-mounted railways and suspended monorails can be also used for loads transported by means of railway locomotives.

Use of the CAD program for collision analysis provides the designer of transportation system with the following benefits:

- Possibility of multiple analyses of collision for changing boundary conditions (localization of railway route in a roadway cross-section, size of transported loads, additional machines and equipment present on a railway route).
- Speeding up of analyses and possibility of documentation of the obtained results.

- Possibility of creation of models of any degree of complexity.
- Determination of real trajectory of load during transportation of large-size materials – outline of the transported load.
- Possibility of making the measurements of obtained collision surfaces to suggest measures indispensable to eliminate the collision.
- Determination of distance of transported material from the potential obstacles.

The limitations of the presented method result primarily from the two-dimensional nature of the operation, which may lead to inaccuracies in detecting potential collisions. Therefore, it is possible to introduce isolines corresponding to the underground working dimensions at desired heights (as a spatial constraint resulting from the geometric characteristics of the road excavation).

In the existing 2D collision analysis module, the results of the analysis are JPG graphic files showing the individual stages and steps resulting from the simulation. It is proposed (future work) to create, as a final result of the simulation, a 2D collision analysis report (MS WORD file), containing both the input data for the analysis and the results of the numerical simulation.

The collision analysis program, developed by KOMAG Institute, can also be used in programs other than AutoCAD (for example Microstation developed by Bentley Systems). In this case, the input data for the collision analysis is exported from Microstation to AutoCAD as a DWG file and the output data (results) is exported from AutoCAD to Microstation as a DGN files.

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